2001

The optical properties of varnishes and their effects on image quality

Collin Day

SIMG 503

Senior Research

The Optical Properties of Varnishes and their Effects on Image Quality

Collin Day
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology

May 2001

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Abstract

Varnishes have been used to alter the appearance of paintings throughout history. Most significantly, they help to level the surface of the painting and reduce the first-surface diffuse scattering of light. This scattering makes a painting appear desaturated and gives it a much lower contrast. Traditionally, varnishes have been made from natural sources, such as tree resins. Over time these varnishes will dull and add a yellow cast. Also, the repeated cleaning and reapplication may hasten the deterioration of the painting, making the choice of varnish crucial in order to restore the painting to its original appearance and retain this appearance over time. Currently, new synthetic varnishes are being used, but they do not always result in the same appearance as natural varnishes.

There is currently a need to assess the various optical properties of synthetic varnishes to help determine the effects they will have on paintings that they may be applied to. This research evaluated the spatial and colorimetric properties of Union Carbide AYAT PVA and Hercules Regalrez varnishes.

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This report is accepted in partial fulfillment of the requirements of the course SIMG-503 Senior Research.
Title: The Optical Properties of Varnishes and their Effects on Image Quality
Author: David Collin Day
Project Advisor: Roy S. Berns
SIMG 503 Instructor: Tony Vodacek

Acknowledgments

I would like to thank my advisor, Roy S. Berns for all his help and guidance. I would also like to thank Peter Burns, members of the Munsell Color Science Labratory and everyone else who gave me a hand.

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Background

Varnishes have been used to help artists change the appearance of paintings and achieve certain aesthetic goals as well as create a protective layer over the painting. Oil-based varnishes have been mentioned in manuscripts dating as far back as to the eleventh century, but became particularly popular during the Renaissance.

Initially, varnishes were often made from natural resins, such as rosin or mastic, and then combined with a drying oil, such as walnut or linseed[1].

Oil varnishes were later replaced by “spirit varnishes," which were varnishes made of the same types of resins, but now added to a solvent of turpentine [1]. Both oil and spirit varnishes have problems associated with their use.

For example, oil varnishes turn yellow or brown over time, thus changing the overall appearance of colors underneath. Oil varnishes become insoluble which is caused by cross-linking. Although spirit varnishes have the same drawbacks, they remain soluble over time, but in order to remove and replace them, solvents stronger than the varnish itself must be used.

These solvents can cause leaching and eventually destroy the underlying painting.

Because of the aforementioned drawbacks, it has become necessary to identify varnishes with properties that emulate natural varnishes in order to remain true to the artist's vision. It is also important that they remain stable and last for a much longer period of time. This will reduce the need for cleaning and reapplication, which ultimately leads to better conservation of the painting. Currently, there are several different synthetic and natural resins being used.

These include Dammar, Mastic,chemically reduced ketone resins, and hydrogenated hydrocarbon resins. Each results in a different appearance caused by the differences in refractive index and molecular weight. It has been found that varnishes with a higher refractive index and low molecular weight provide more desirable results [1].

Theory

Function of Varnishes

In order to understand how the surface properties affect the visual appearance of paintings, consider the following diagrams that show the path of the light caused by a varnish. In the first diagram, the varnish is smooth and the light reflecting at the angle opposite the angle of incidence is considered to be specular reflection [2].

In figure 2, the varnish is no longer smooth and the light is no longer reflecting in the specular direction. Instead, it is scattered in many directions, thus making the light more diffuse, reducing the gloss and apparent chroma of colors within the painting.

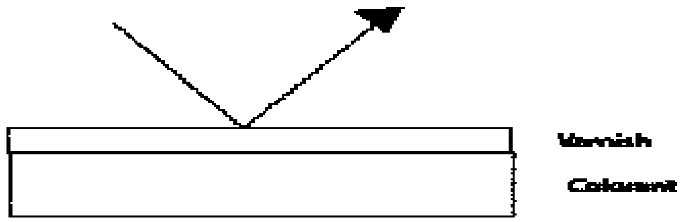


Figure 1 – Smooth Varnish – First Surface Reflection

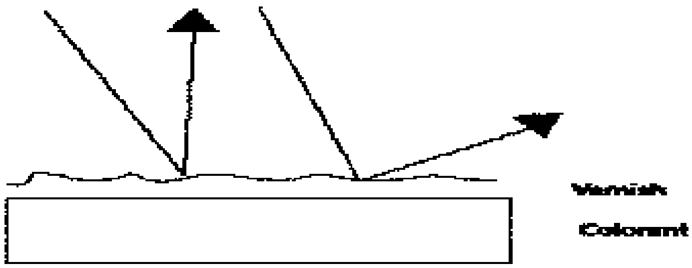


Figure 2 – Rough Surface – First Surface Reflection

Research on the various optical properties of various varnishes is particularly useful to individuals involved in conservation science. It is useful to have an idea of how a particular varnish will affect a painting before it is applied.

A conservator who has an idea of the response of a particular varnish and knows the material of the painting will be able to safely apply an appropriate varnish that will restore its original appearance and minimize leaching due to application and later removal.

Spatial Analysis

Generally, the apparent sharpness of an image is a subjective quality. Over the years, objective measurements of sharpness have been created.

For this experiment, the Cascade Modular Transfer (CMT) Acutance, proposed by Gendron[5], was used. This procedure follows the understanding that a system modulation transfer function (MTF) is simply the cascade or multiplication of the system component MTF's. In order to assign a usable metric to the varnish, the Spatial Frequency Response (SFR) of the system from the PIMA Image Analyzer was used[Pima Reference Here]. The SFR has been proven to be an analagous metric to the MTF[4]. The varnish SFR was then isolated and used in the CMT measurement.

Colorimetric Analysis

The effect of a varnish can be determined by using appropriate color difference equations. In order to obtain these data without performing direct contact measurements, it was decided that colorimetric data could be derived through image information.

By optically obtaining these measurements, a better simulation of viewing conditions could be achieved, making the overall simulation more realistic.

Methods

Varnish Mixture

The Regalrez and PVA were chosen for the difference in molecular weight between the two. The PVA has a much higher molecular weight than the Regalrez. The Regalrez was mixed 1 to 1 ratio with paint thinner by weight. The PVA was mixed 1 part PVA to three parts Arcosolv PM solution. These mixtures attempt to take the difference in molecular weight into account so that when each layer dries, the layers will be of an equal thickness.

Target Creation

It was necessary to create test targets to which the varnish could be applied because a major idea behind this experiment is that the data be taken from reflection objects. For the spatail analysis, slant edge targets were made by applying a layer of matte white to a smooth card and then an edge of approximatley five degrees from normal was made with black paint. The target for the colorimetric analysis was made from Sherwin Williams latex house paint, chosen for its dark colors and matte properties, applied to a regular canvas. Varnish was applied to the targets using a .003 inch draw-down bar. These methods were chosen to help simulate actual working conditions.

Image Acquisition

In order to image the targets, an IBM Pro – 3000 camera was used. This camera is a line scan camera that generates a 12-bit image per color channel.

Colorimetric Evaluation

The first step in the colormetric evaluation was to determine the actual X, Y, and Z values of the Gretag Macbeth ColorChecker Color Rendition Chart being used. This was done by integrating the spectral reflectance of each patch with the spectral output of the lamps illuminating the target and the CIE color matching functions for the 1931 two degrees standard observer and then multiplying by a normalization constant. This integration was performed over an interval of 380nm to 730nm at 10 nm steps. The following equations were used:

$$X = k\sum_{\lambda} S_\lambda R_\lambda \bar{x}_\lambda \Delta\lambda$$

$$Y = k\sum_{\lambda} S_\lambda R_\lambda \bar{y}_\lambda \Delta\lambda$$

$$Z = k\sum_{\lambda} S_\lambda R_\lambda \bar{z}_\lambda \Delta\lambda$$

$$k = \frac{100}{\sum_{\lambda} S_\lambda \bar{y}_\lambda \Delta\lambda}$$

$$\Delta\lambda = 10\text{nm}$$

where S_l is the spectral output of the source illumination, R_l is the spectral reflectance, and x,y,and z bar are the appropriate CIE color matching function.

The next step was to determine the values which would linearize the digital counts of the camera. This was done by applying the following gain–gamma-offset equation to the digital counts given by the camera and then minimizing the RMS tristimulus error of the linearized digital counts of the Macbeth grayscale.

$$(\frac{R}{B}G)^r$$

where R=raw digital count, B=max digital count (2^bit depth –1), G=gain.

These values were then used to generate a 3x9 pseudo inverse matrix that could be used to transform linear digital counts to CIE XYZ space.

Third, the XYZ values of the unvarnished and varnished color target were found. These values were then converted to CIE L*a*b* space and the color difference can be found using the following equations:

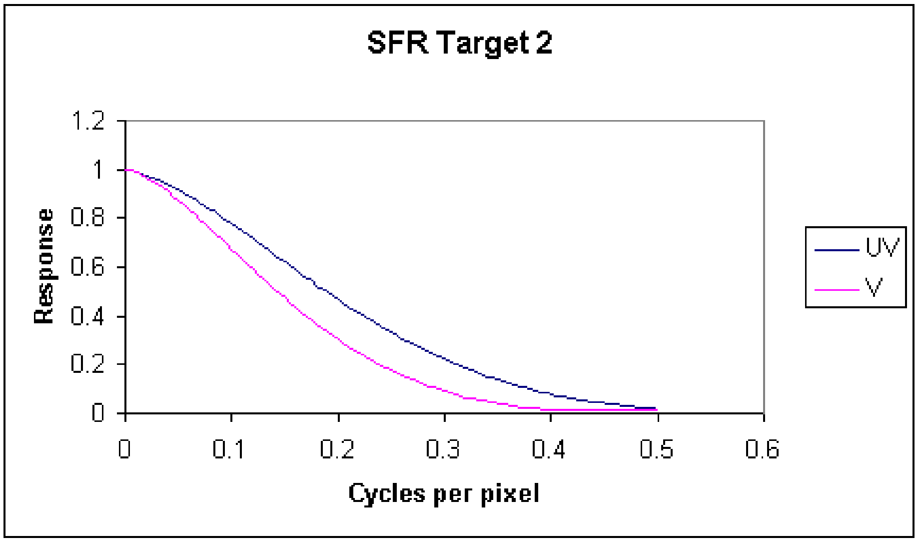
$$L^* = 116(Y/Y_n)^{1/3} - 16$$
$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$
$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$$
$$\Delta L^* = L^*_{measured} - L^*_{standard}$$
$$\Delta C_{ab}^* = C_{ab}^*_{measured} - C_{ab}^*_{standard}$$
$$\Delta H_{ab}^* = \frac{a^*_{measured}\, b^*_{standard} - a^*_{standard}\, b^*_{measured}}{[.5(C_{ab}^*_{measured}\, C_{ab}^*_{standard} + a^*_{measured}\, a^*_{standard} + b^*_{measured}\, b^*_{standard}]^{1/2}}$$
$$\Delta E^*_{94} = [(\frac{\Delta L^*}{k_L S_L})^2 + (\frac{\Delta C_{ab}^*}{k_C S_C})^2 + (\frac{\Delta H_{ab}^*}{k_H S_H})^2]^{1/2}$$
$$k_L = k_c = k_h = 1$$
$$S_L = 1$$
$$S_c = 1 + .054 C_{ab}^*$$
$$S_H = 1 + .015 C_{ab}^*$$

where the unvarnished target was the standard and the varnished target was used as the measured.

Spatial Evaluation

In order to evaluate the SFR of the slant edge targets with the Image Analyzer plug in, the 12 bit camera data had to be converted to 8 bit and a new lookup table for the plug in had to be created. This was necessary because the plug in was designed only to accept 8 bit input. After this was done, the image's SFRs were found in the green (luminance) channel.

The CMT Acutance of the varnished and unvarnished target for each specific resin was then computed.

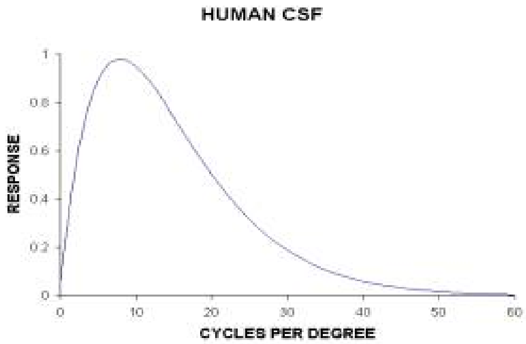


Then, the human Contrast Sensitivity Function was generated using the following equation proposed by

Mannos and Sakrison[6] for its ease of analysis.

$$A(f) = 2.6 \cdot (0.0192 + 0.114 \cdot f) \cdot e^{-(0.114 \cdot f)^{1.1}}$$

f = frequency in cycles per degree



In order to assign a quantitative number to the varnish, these curves are converted to cycles per millimeter, multiplied point by point and integrated. This yields the CMT Acutance.

$$CMT = 125 - 20\log_{10}(200 / MTF_{curve})^2$$

$$MTF_{curve} = \int Varnish_{MTF_{eff}} \cdot CSF_{Human}$$

For the CMT Acutance, a range of 0 to 9 cycles per millimeter was used. Anything outside this was considered noise.

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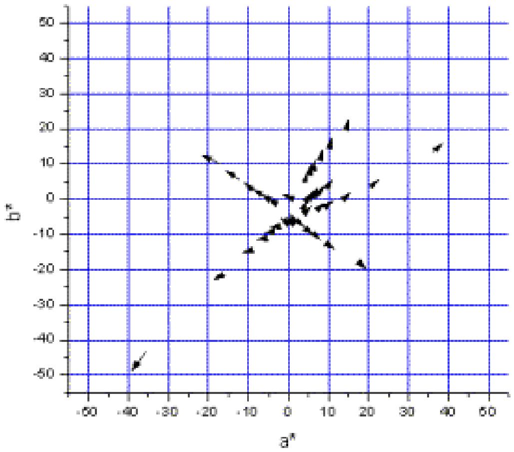
Results

The colorimetric evaluation showed that RegalRez varnish did in fact improve color saturation. The following graph is a vector plot of the beginning and ending a* and b* for each color patch, comparing the unvarnished color target with the varnished color target.



The arrows radiate out from the center and there is almost an equal change in both a* and b*, which is analogous to an increase in chroma.

The spatial response analysis did not show a significant difference between the PVA or Regalrez.. The target used with the Regalrez had a CMT of 29.7 unvarnished and a CMT of 27.8 varnished. The target used with the PVA had a CMT of 29.7 unvarnished and a CMT of 28.2 varnished. These values show no significant difference between the varnishes and also show that the varnish actually decreased the spatial response.

sample SFR target

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Discussion

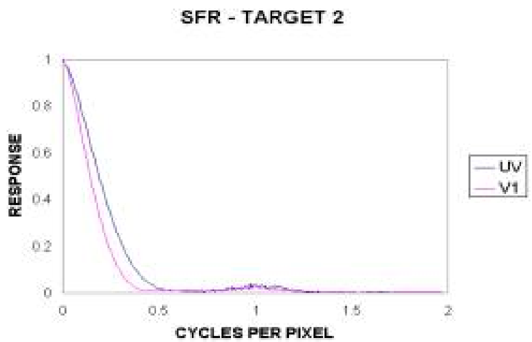
The colorimetric evaluation yielded the type of results that were expected. It is apparent that the Regalrez varnish did help level the rough surface of the painting, which reduced the scattering of the light incident on the target.

The SFR analysis did not yield the expected results. The two varnishes for this experiment were chosen because of their difference in molecular weight. It was expected that the PVA, whose molecular weight is much higher than the Regalrez varnish, would show a significantly lower CMT Acutance result. Instead, they only differed by .3.

Currently, it is thought that the varnishes were applied too thickly on the targets, thus making both varnishes to appear to behave in the same manner. It is necessary to devise a way to consistently apply the varnish in a much thinner layer.

Another unexpected result that was noticed was that the varnished target had a worse SFR than the unvarnished target.

This conflicts with the idea that the varnish decreases the scattering of light, which would ultimately increase resolution.



The methods used for the colorimetric analysis seemed to be quite acceptable. They were consistent with qualitative observations.

Because the method for spatial frequency analysis is a rather new idea, there are many aspects that could be altered to try and achieve better results.

First, there was the before mentioned varnish thickness and concentration of varnishes in solution. These could both be reduced to produce a much thinner layer of varnish that may lead to better results. Also, the viewing distance of the camera could be made closer to the target. Because the variations that are being looked for are very subtle, they might be somewhat pronounced if the image area of the slant edge target was enlarged.

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Conclusion

Based on the results of the colorimetric analysis, the methods used are effective and can be used to evaluate the effect the varnish will have on the painting with respect to color change.

The methods used for evaluating the SFR of the varnish needs to be improved. An analysis using this method may still be viable, but changes need to be made to the process and weaknesses need to be found. Further work should include determining the proper concentration of the varnish, the proper thickness, the height of the camera, etc. Once these parameters are found, an analysis using these methods may be used.

Finally, further work should also involve a record of the effect that cleaning and reapplication of the varnish multiple times may have on the painting and the spatial frequency response. These data could also prove to be useful to individuals who routinely use varnishes, such as painters and conservators.

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References Cited

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3. Berns, Roy S., Billmeyer and Saltzman's Principles of Color Technology 3rd Ed., John Wiley & Sons, Inc., NY, 2000

4. Burns, Peter D., "Slant-Edge MTF for Digital Camera and Scanner Analysis," Proc. IS&T PICS Confrence (2000) 135-138

5. Gendron, R.G., "An Improved Objective Method for Rating Picture Sharpness: CMT Acutance," Journal of the SMPTE 82 (1973) 1009-1012

6. J. L. Mannos, D. J. Sakrison, ``The Effects of a Visual Fidelity Criterion on the Encoding of Images", IEEE Transactions on Information Theory Vol. 20, No 4, (1974) 525-535

Appendix
datagathering16mw.pro - file which collects digital counts
calibrate.pro - file which takes information about a standard and generates the color transform matrix
MTF_prep.pro - Converts file to 8 bit for MTF / SFR analysis
CMT_calc.pro - Calculates CMT acutance
colorimetry.pro - Calculates various colorimetric values

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